Storm-scale pseudo-GLM lightning assimilation

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11th JCSDA Science Workshop on Satellite Data Assimilation
June 6, 2013

Two methods of lightning data assimilation are implemented:

1. Using lightning (time/location) to force convection initiation by nudging in water vapor where lightning is observed but convection is absent in the model. Forcing is maintained for 10s of minutes to achieve a model response to sustain the storms. (See Fierro et al. 2012, Mon. Wea. Rev.) Using ENTLN total lightning as stand-in for GLM.

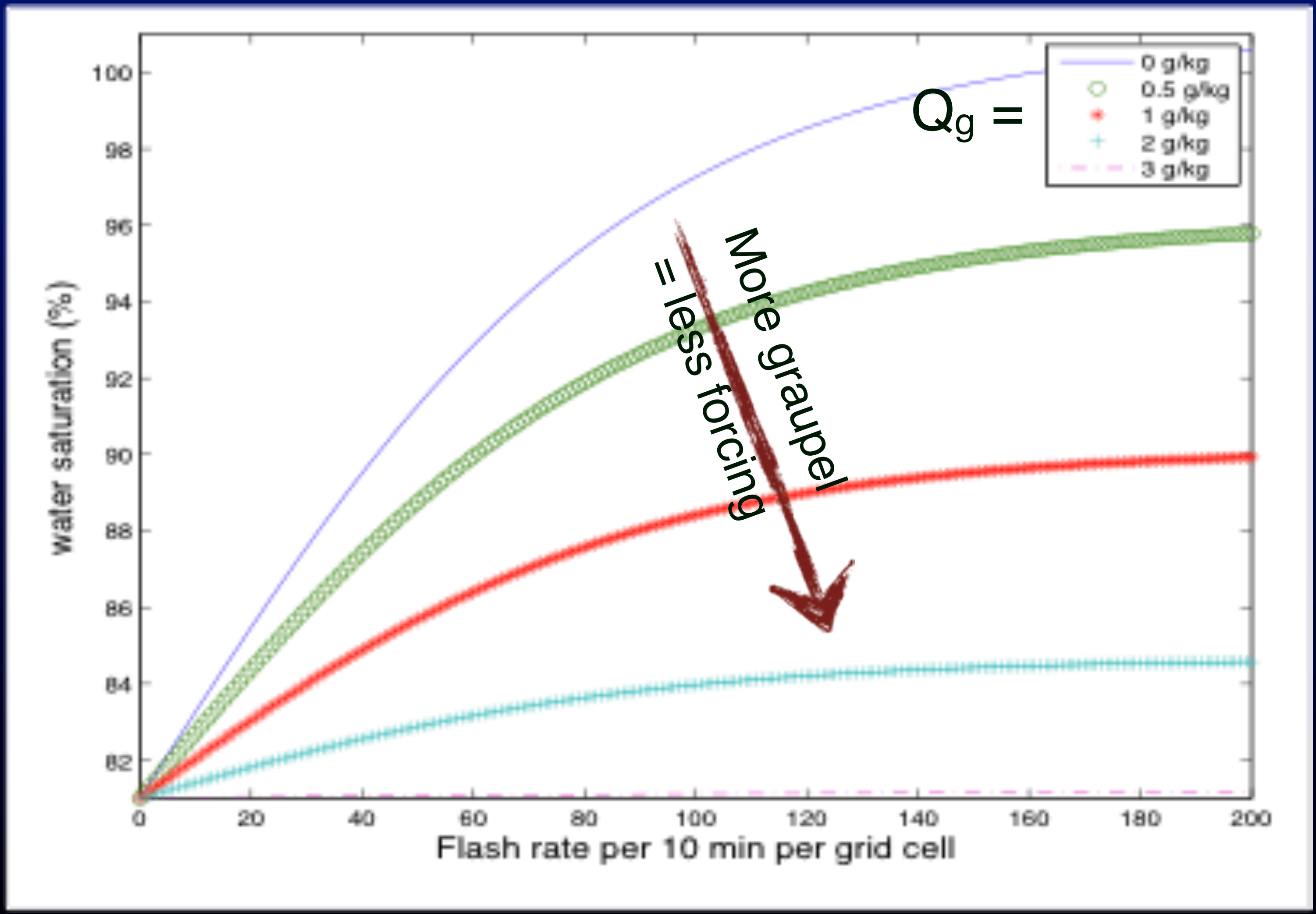
2. Ensemble Kalman Filter to modulate convection (e.g., strengthen or weaken) in the ensemble members. Ensemble covariances provide adjustments to all state variables (e.g., temperature, water vapor, winds, liquid water and ice particles). Pseudo Geostationary Lightning Mapper (p-GLM) data (derived from LMA) are assimilated on 1-3 minute intervals.

Lightning assimiation nudging function

Water vapor mixing Q_v within the 0°C to -20°C layer was increased as a function of 9-km gridded flash rates N_{flash} (X) and simulated graupel mass mixing ratio Q_g and saturation vapor mixing ratio Q_{sat}. Increasing Q_v at constant temperature T increases buoyancy (virtual potential temperature θ_v) and ultimately generates an updraft.

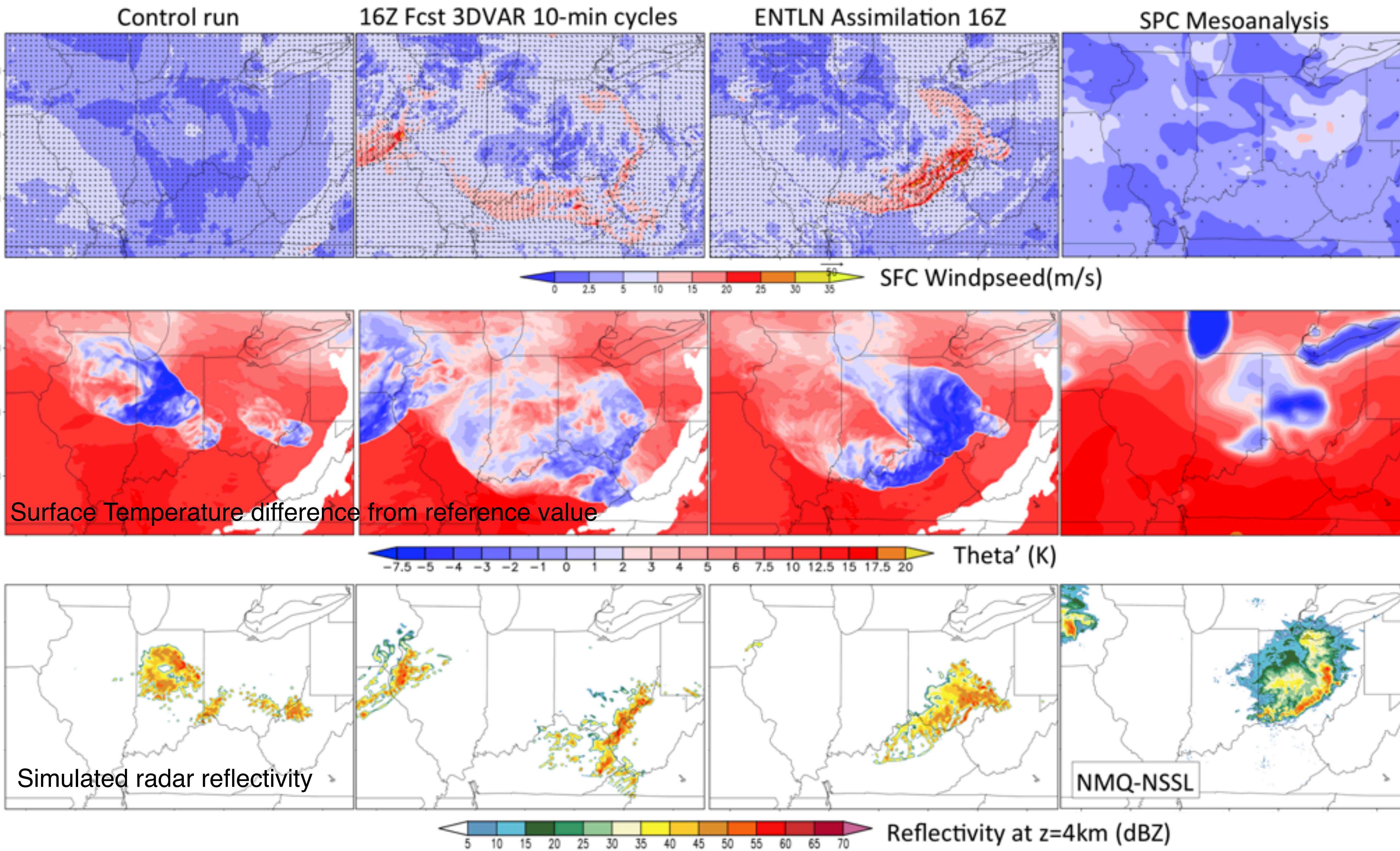
$$Q_v = AQ_{\mathrm{sat}} + BQ_{\mathrm{sat}} \tanh(CX)\,[1 - \tanh(DQ_g^{\alpha})]$$

-Only applied whenever simulated RH ≤ A*Qsat and simulated Qg < 3 g/kg.
-A controls minimum RH threshold (here 81%).
-B and C control the slope (how fast to saturate)
-D affects how much water vapor (Qv) is added at a given value of graupel mixing ratio (Qg).



29 June 2012 Derecho Event

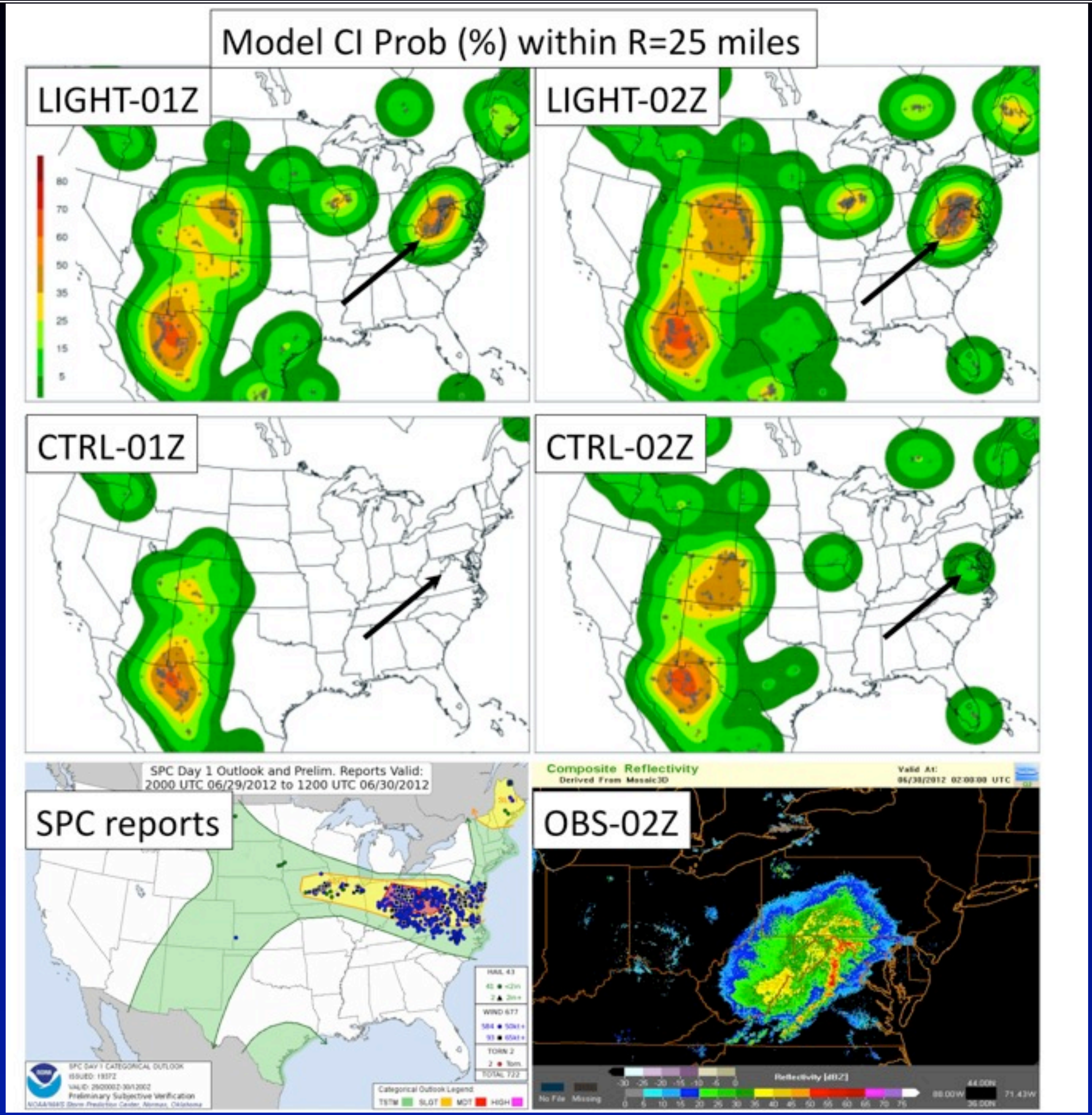
Comparison of 3-km resolution forecasts at 22 UTC: No Assimilation (Control, 14 UTC starting time), 3D-var assim. of radar data (10-minute cycling, 14-16UTC), and lightning (ENTLN system) assimilation (14-16 UTC).



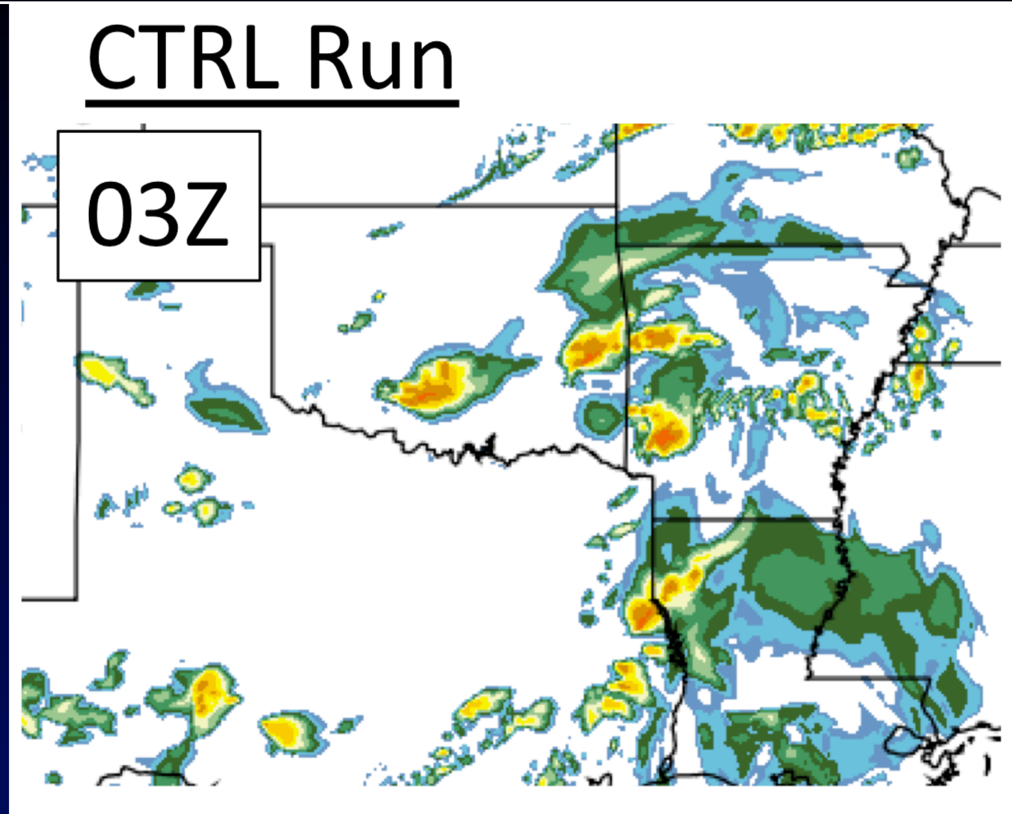
Real -time implementation into WRF-NSSL 4-km CONUS runs

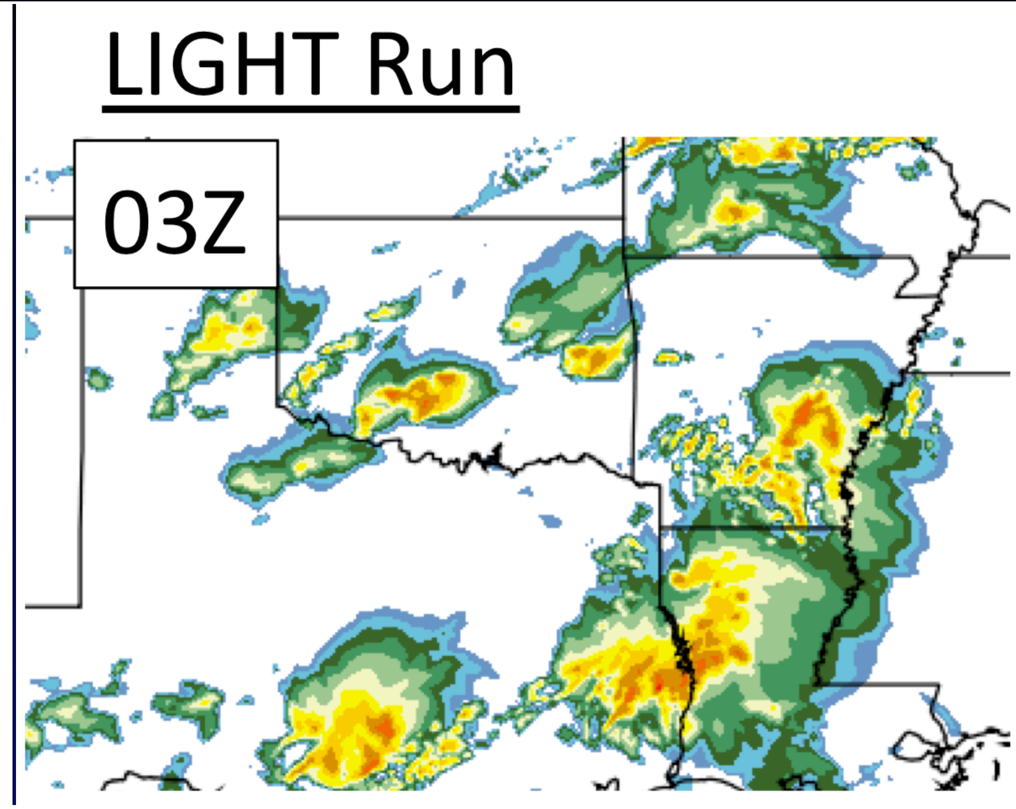
A quasi-operational system has been set up as a parallel forecast to the daily NSSL convection-allowing forecasts (4-km horizontal grid spacing), initialized at 00 UTC. Lightning data (ENTLN) are assimilated for the first two hours (0-2 UTC) of forecast to nudge in deep convection.

Here again is the 2012 Derecho event in terms of convection initiation (CI) probability. The lightning assimilation spins up the ongoing severe convection (arrow) that fails to emerge from the initial condition alone in the control case.

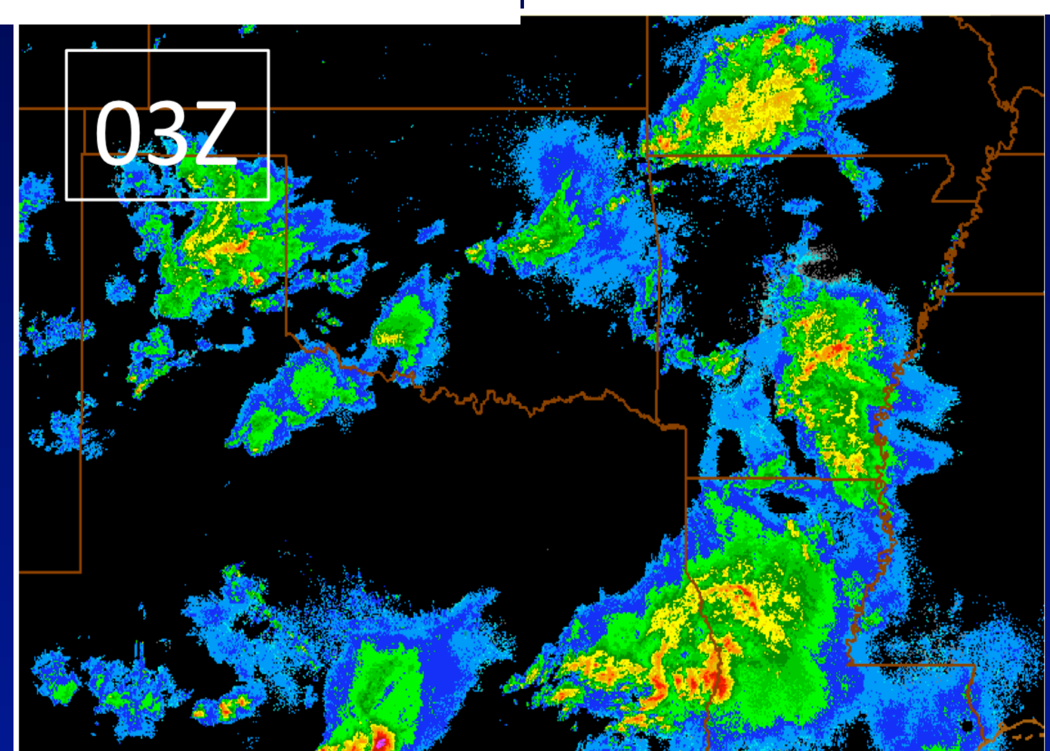


Real -time example: 10 May 2013



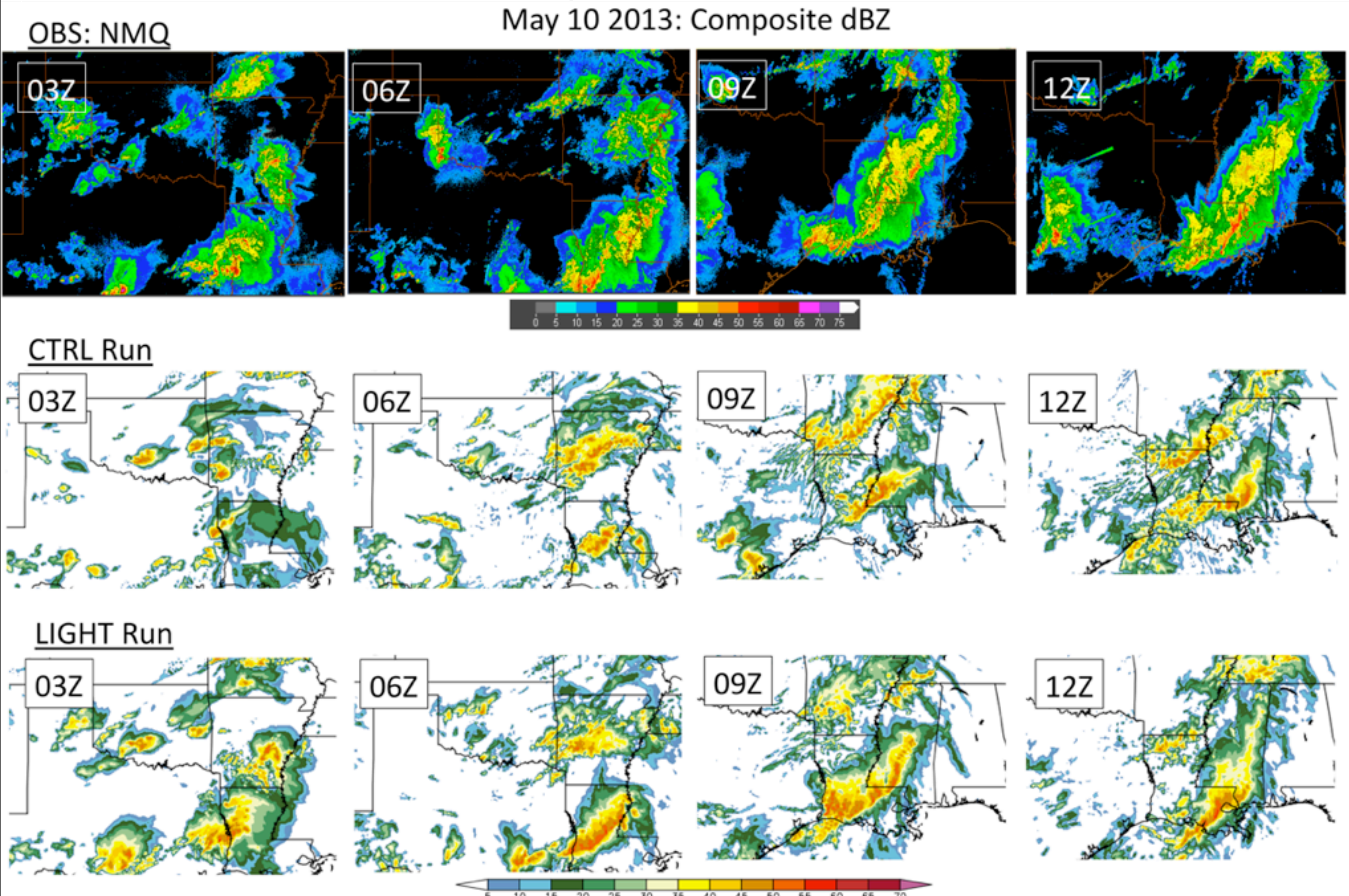


Radar mosaic

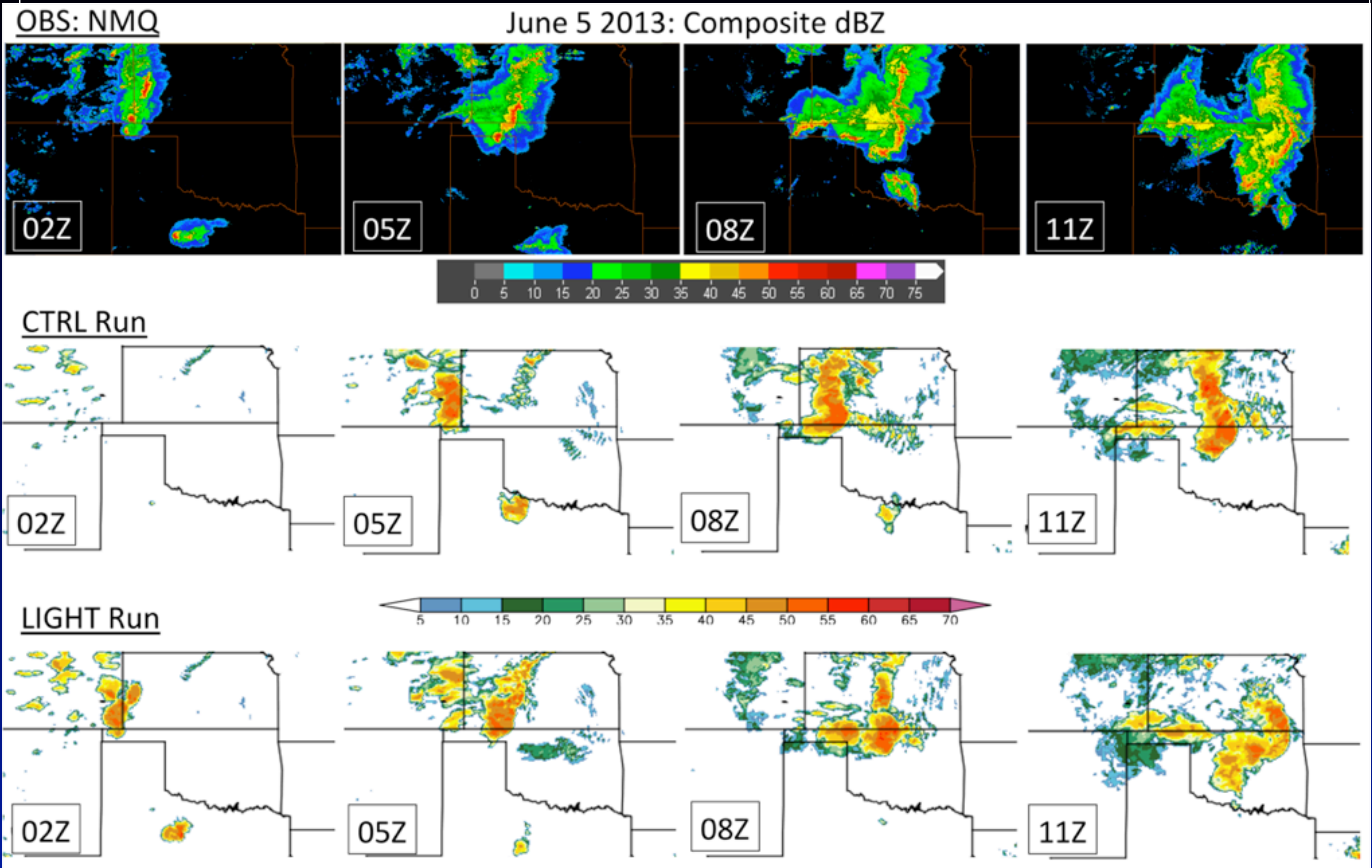


Real-time runs should generate sufficient warm-season data for evaluation of forecast benefit.

Real -time example: 10 May 2013



Real -time example: 5 June 2013



Ensemble Kalman Filter (EnKF) Assimilation

EnKF offers a means to an observation to adjust all state variables via covariances with a corresponding simulated observation (here, lightning flash extent rates) from the ensemble members. It cannot generate convection by itself, but can modulate convection forced by other means or help to suppress spurious deep convection.

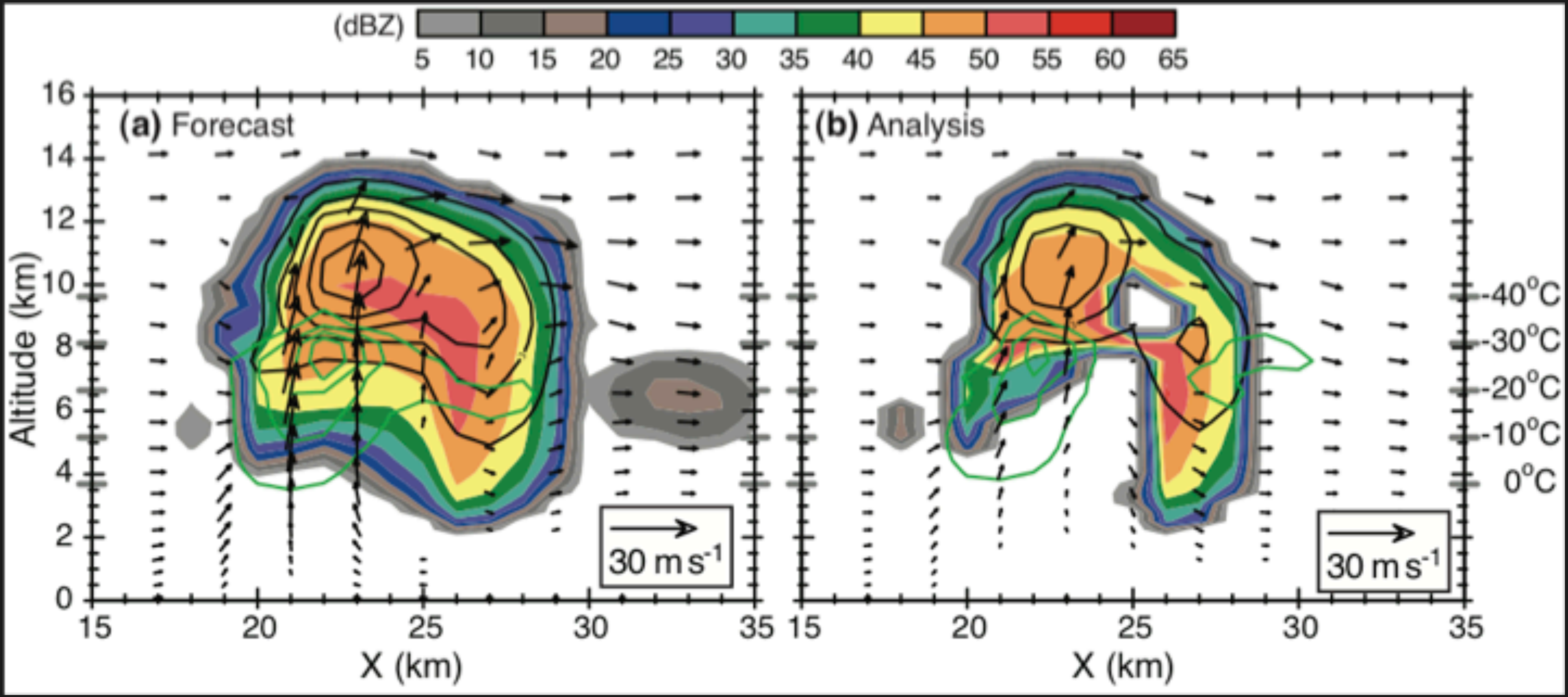


Figure: Observing Systems Simulation Experiment (OSSE): Example of a single lightning assimilation cycle damping a spurious storm cell in an ensemble member. Reduced updraft (vectors) and graupel mass (black contours) and radar reflectivity

Pseudo-GLM EnKF Assimilation

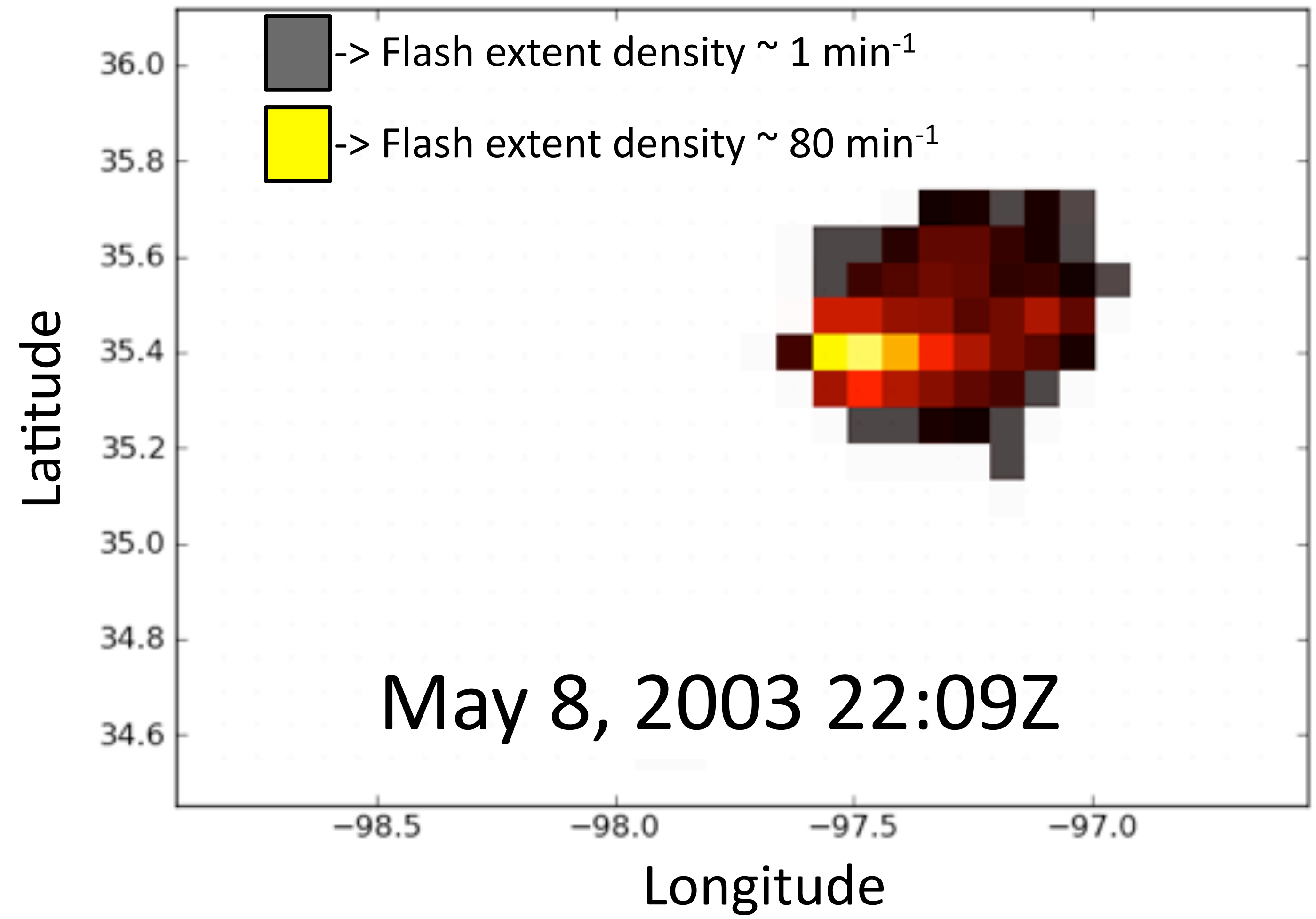
P-GLM flash extent density observations were generated from Lightning Mapping Array (LMA) data, using a flash separation algorithm (MacGorman et al 2008) to specify individual flashes.

Various linear relationships between graupel mass and flash rate, graupel echo volume and flash rate, and non-inductive charging and flash rate were tested. Good results for strong and weak convection tests were found with the relationship:

FED = (0.017)*(graupel volume)

Here, graupel volume is the sum of grid cells with graupel mixing ratio > 0.5 g/kg in a 16-km box centered on the p-GLM pixel.

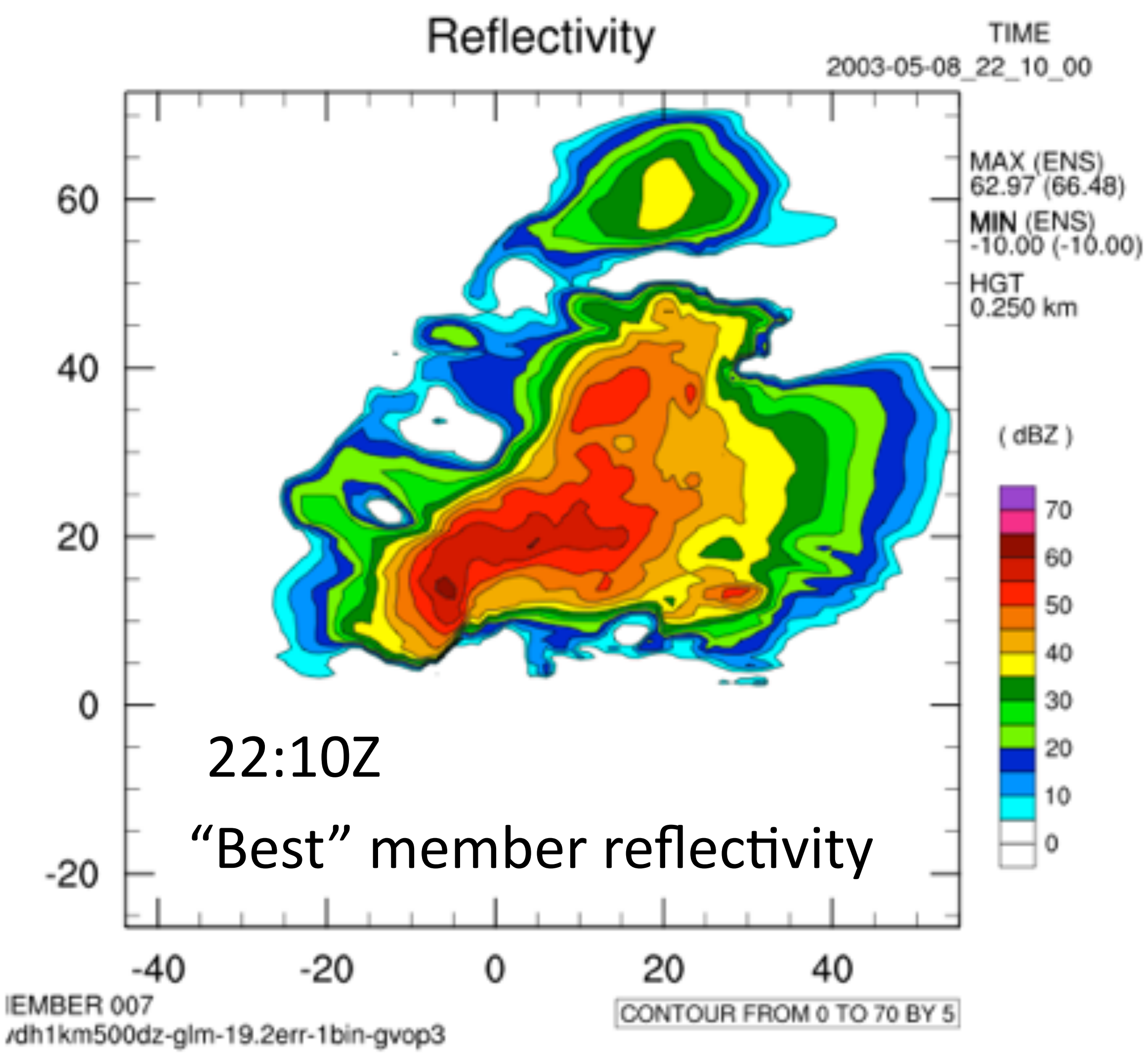
Ensemble has 40 members at 1-km horizontal resolution. Comparison assimilation tests with radar radial velocity were also performed. Cloud model is COMMAS with NSSL 2-moment microphysics.

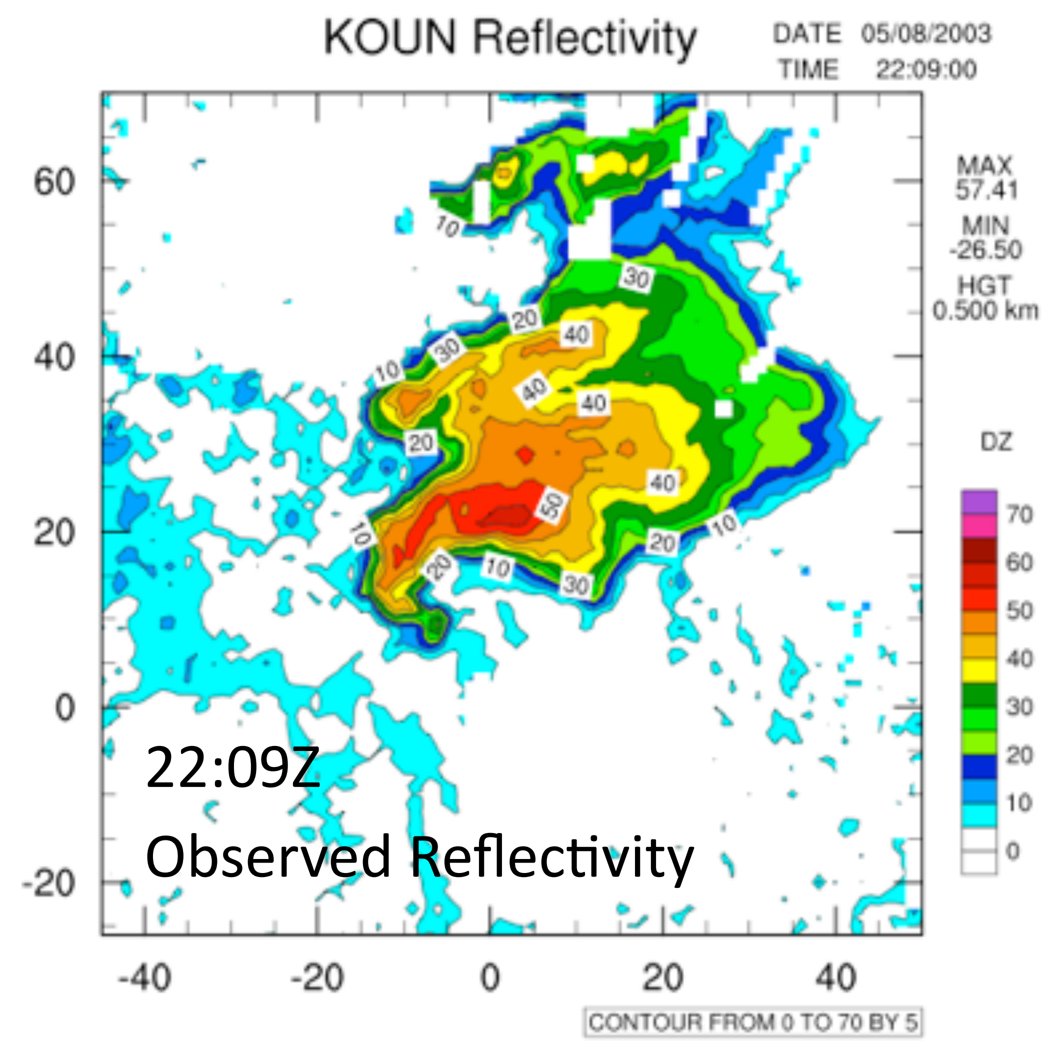


Example of pseudo-GLM Flash extent density (FED) derived from Oklahoma LMA for 8 May 2003 tornadic supercell storm.

P-GLM EnKF: 8 May 2003 Supercell

Low-level analysis of radar reflectivity around the time of the first tornado (Moore/Oklahoma City, OK EF4 tornadic storm)

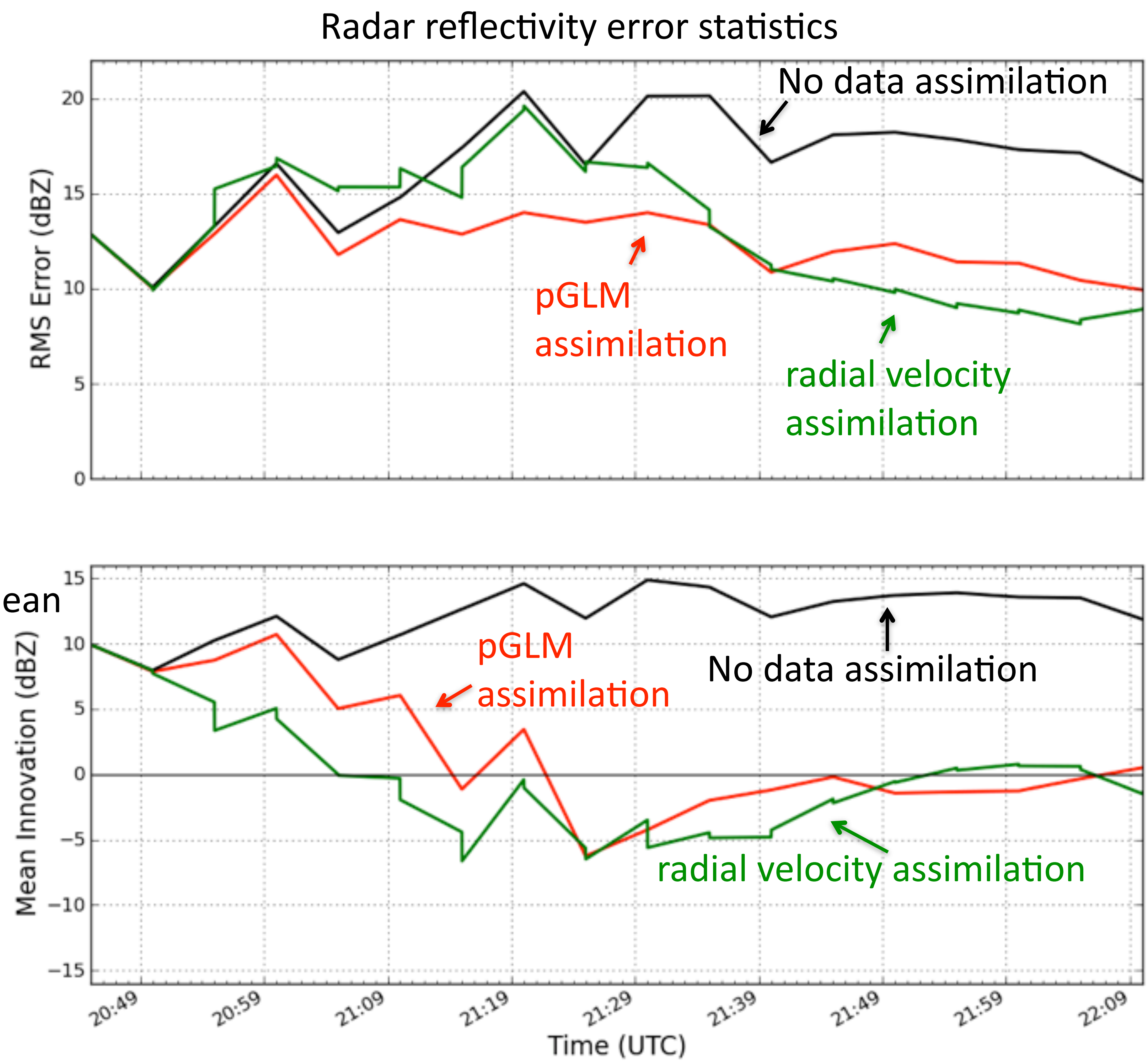


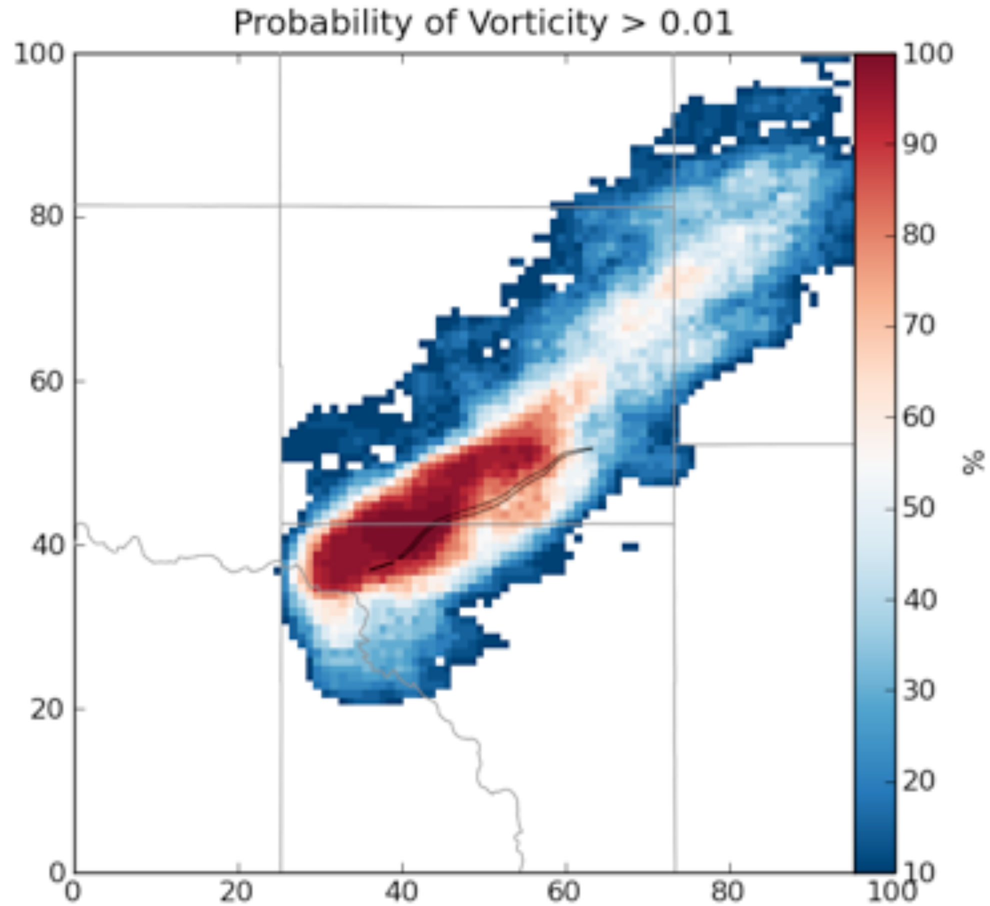


Some broadening of the storms is expected from the 8-km resolution of the pseudo-GLM data. Excessive coverage of high-reflectivity regions is not unexpected, but also is rather good for a simple linear lightning observation operator.

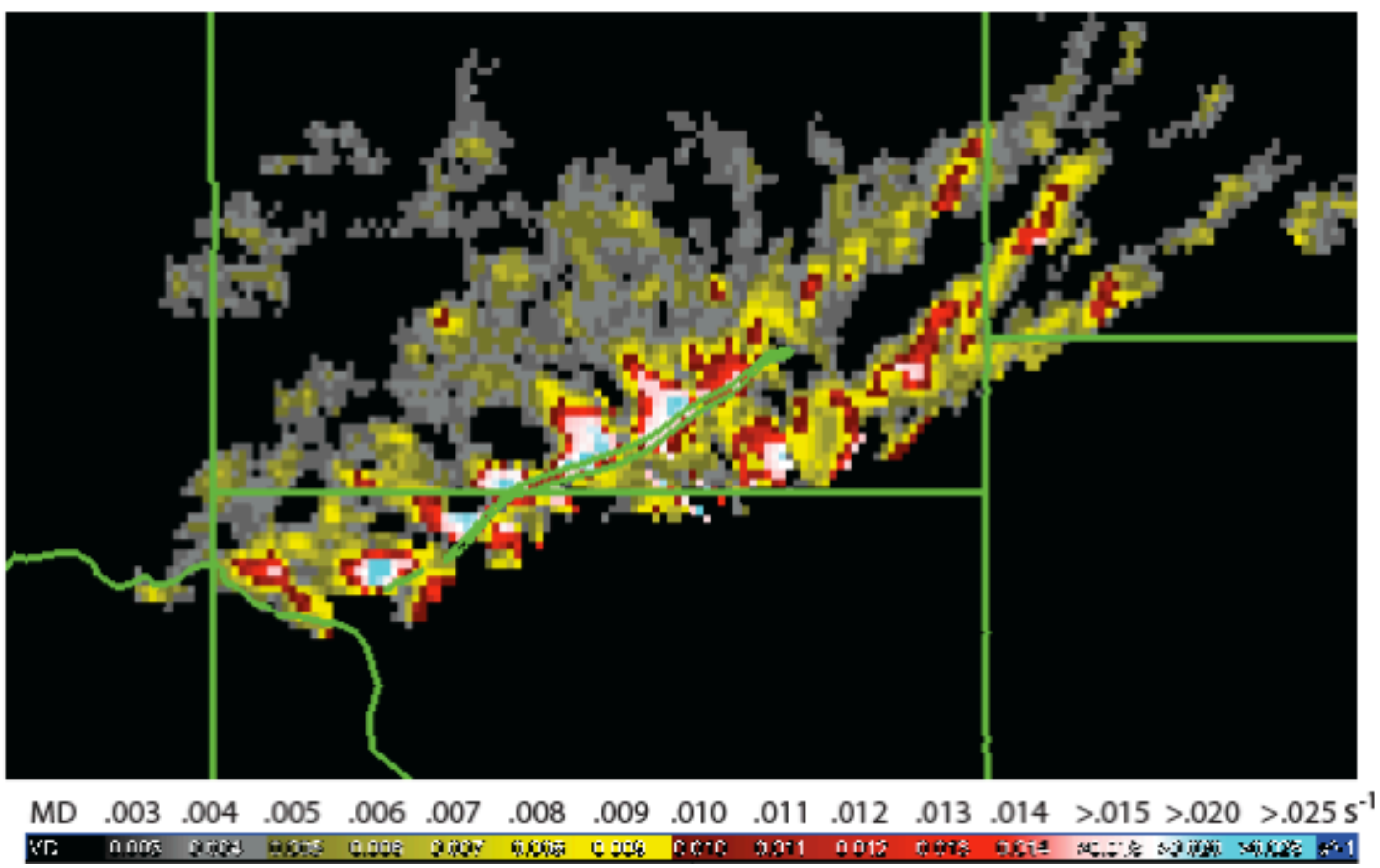
8 May 2003: 1 minute pGLM data assimilation vs. radar radial velocity assimilation

Innovation = Ob - Model Mean





Ensemble probability of Vorticity > 0.01 s^{-1} at 1.25 km AGL from 2200 UTC to 2300 UTC, assimilating 1 minute pGLM data with graupel volume observation operator. Tornado track is given by thin black outline near center of plot.



WDSS-II 0-2 km rotation track derived from KTLX radial velocity data from 2200 UTC to 2300 UTC. Tornado track given by green outline near center of plot. (From Yussouf et al. 2013)

Summary:

Lightning effectively identifies deep convection and is useful for forcing convection in the early hours of a forecast. Sustained nudging of water vapor forms updrafts and allows storms to develop in a balanced manner within the model. For simple convection initiation, it is more efficient, e.g., than 3D-VAR radar analysis.

The Ensemble Kalman Filter method can modulate convection (e.g., strengthen or weaken) and help suppress spurious storms using lightning, radar, or other data. It requires an ensemble, which is computationally expensive, but eliminates the need to develop direct algorithmic adjustments of state variables (updraft, moisture, temperature, etc.) or complex 4D-var adjoint models.

Some next steps: Evaluate lightning nudging over numerous days to evaluate impact (e.g., 24-hour rainfall); Run forecasts from EnKF analyses; Look at landfalling tropical cylcones (e.g., Isaac 2012).

Reference: Fierro, A. O., E. R. Mansell, C.L. Ziegler, and D.R. MacGorman, 2012: Application of a Lightning Data Assimilation Technique in the WRF-ARW Model at Cloud-Resolving Scales for the Tornado Outbreak of 24 May 2011, Mon. Wea. Rev. vol. 120, 2609-2627.